AsteroidFinder:
Unveiling Objects Interior to Earth’s Orbit

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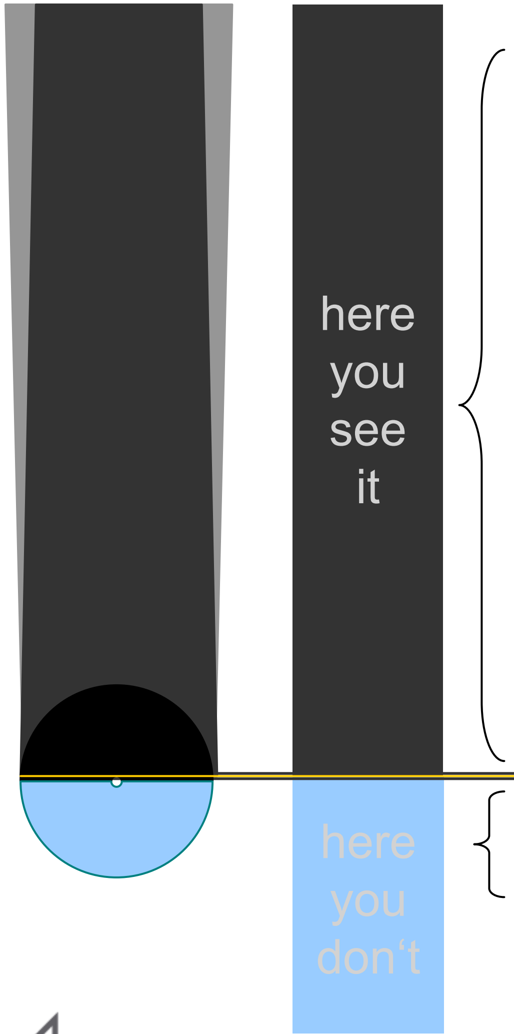
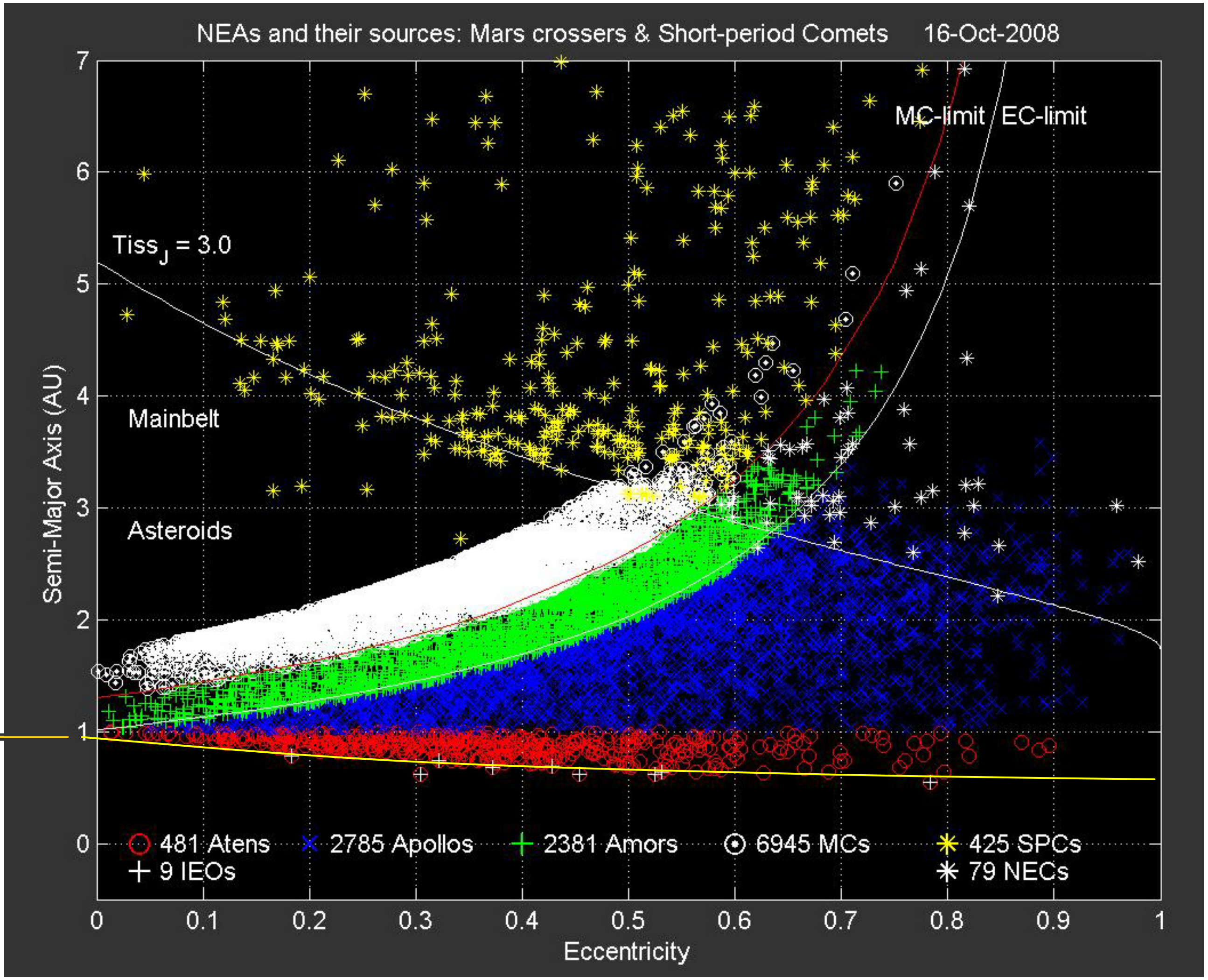
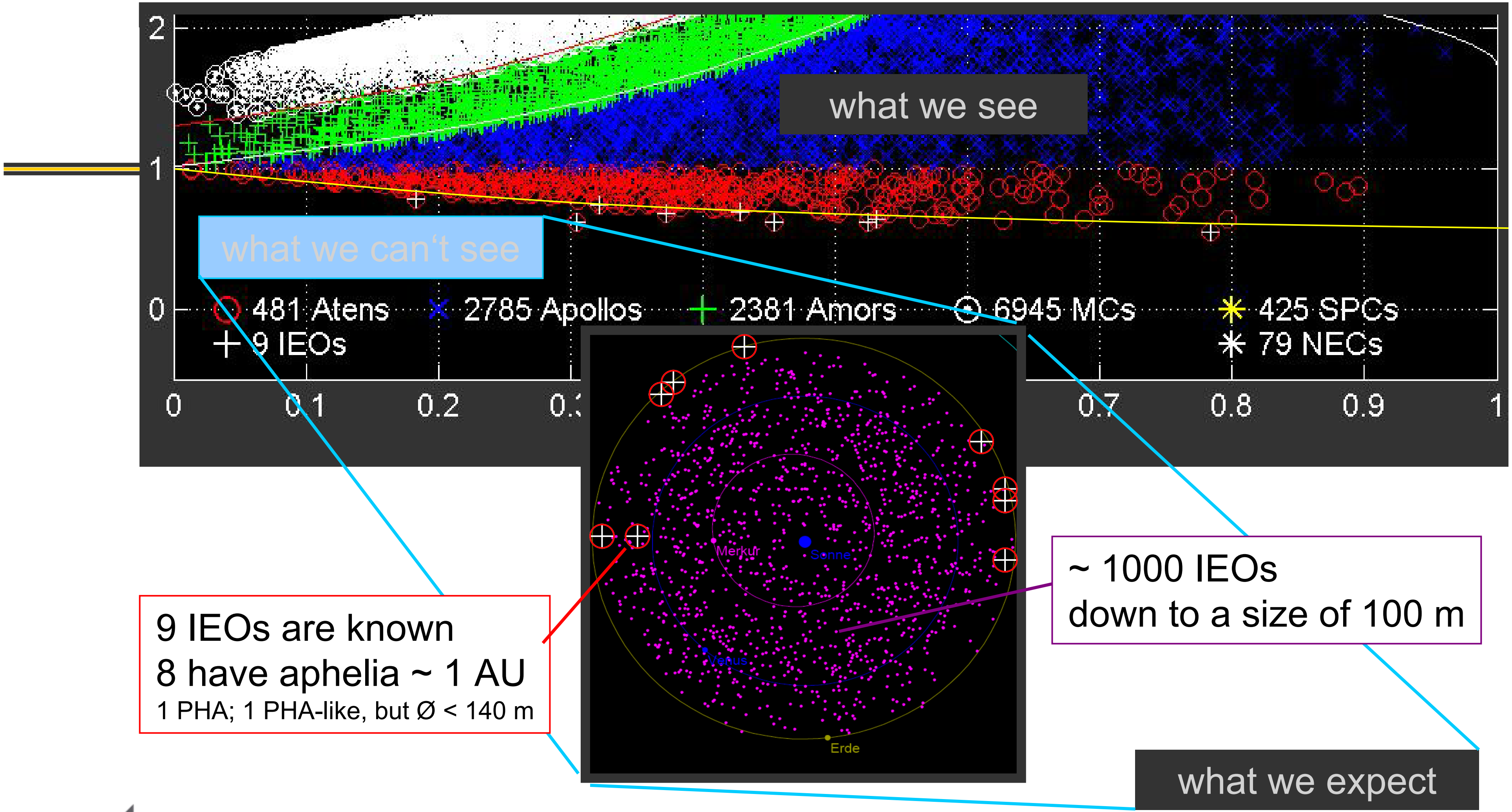
in der Helmholtz-Gemeinschaft

NEO Mitigation? - Shoot later. Ask first.

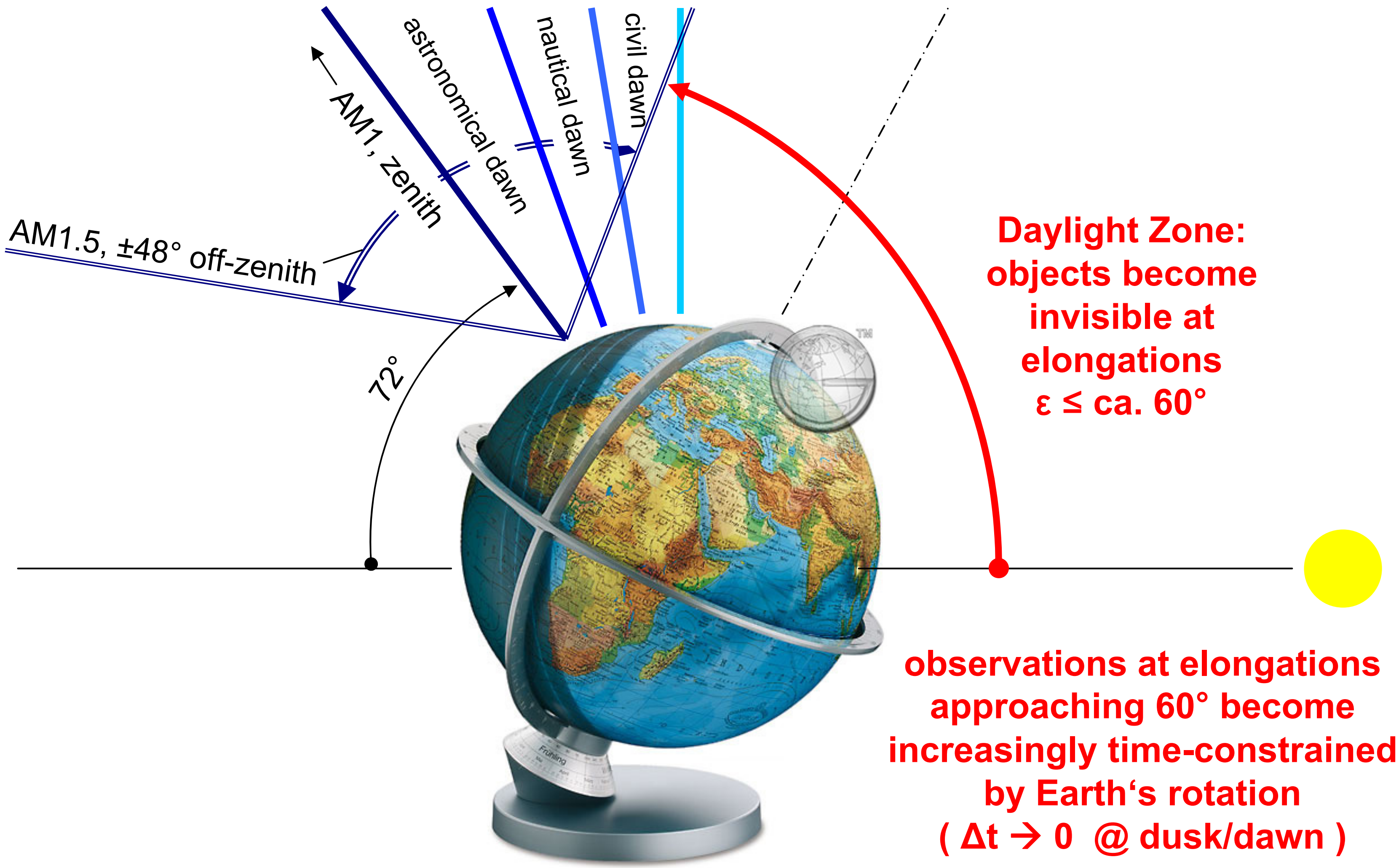




… and keep asking: Can I see them at all?!



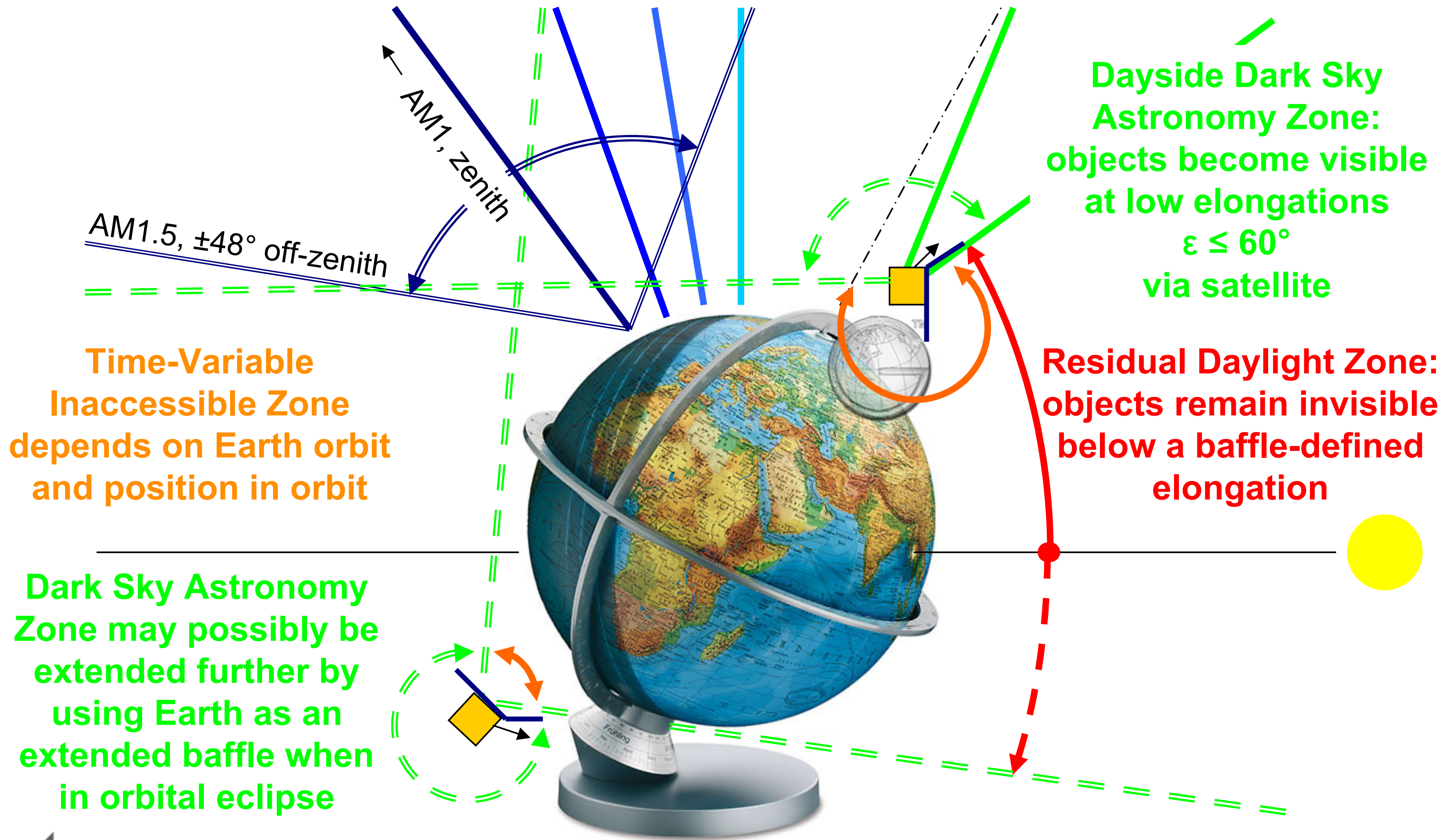
the sky is the limit



Daylight Zone: objects become invisible at elongations ε ≤ ca. 60°

observations at elongations approaching 60° become increasingly time-constrained by Earth‘s rotation (Δt → 0 @ dusk/dawn)

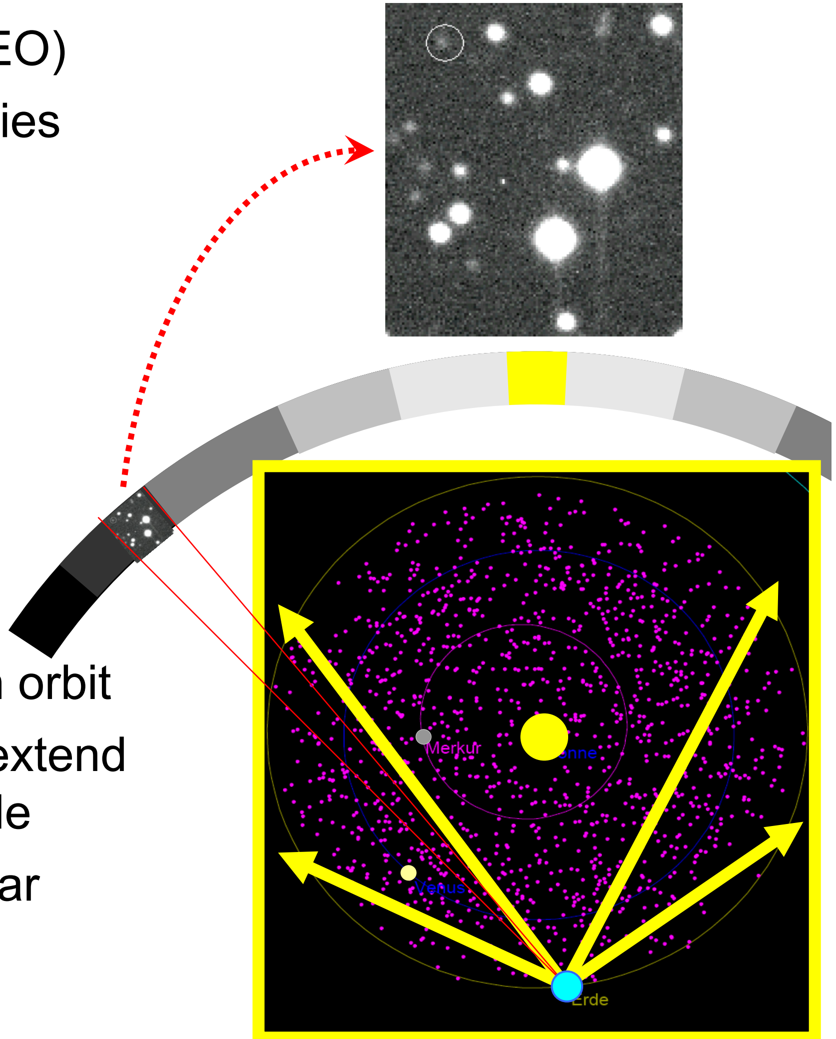
above the sky: AM0 on a sunny day



the task: unveiling the planets at day

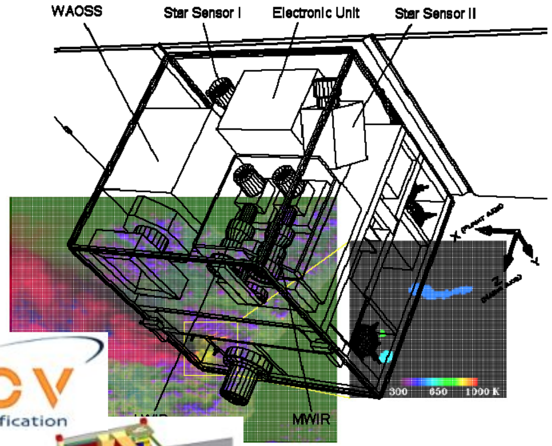
- find objects Interior to Earth‘s Orbit (IEO)
- determine and catalogue their properties
    - population
    - orbital properties
    - size-frequency distribution
    - classes, groups, and families

- make use of the non-IEO background for night-like dayside astronomy
    - detect and track objects in Earth orbit
    - detect and track non-IEOs and extend known orbital arcs on the dayside
    - detect and monitor variable stellar objects (stars, supernovae,…)
    - monitor diffuse background

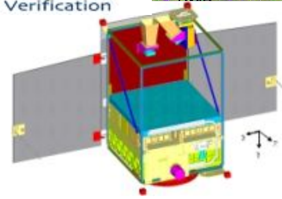


the foundation: 7 years of BIRD
the framework: „Kompaktsatellit“ programme

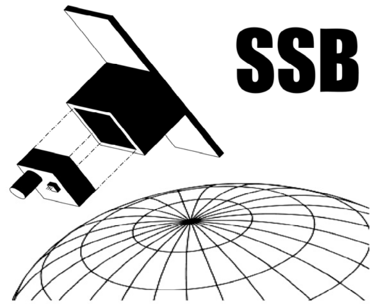
- *B*i-spectral *I*nfra*R*ed *D*etection
- optical bench for pixel-co-aligned dual band near, mid, thermal IR cameras
- design life 1 year
- reduced operability after 2 ¼ years
- remains recoverable after 7 years



On Orbit Verification

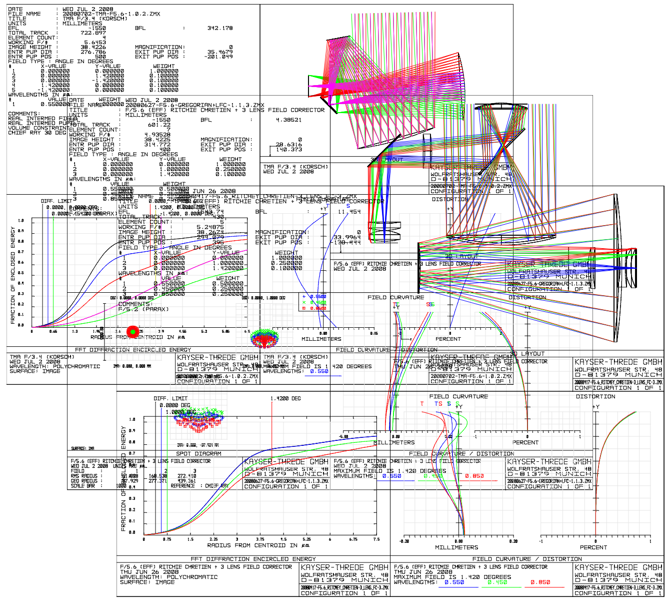


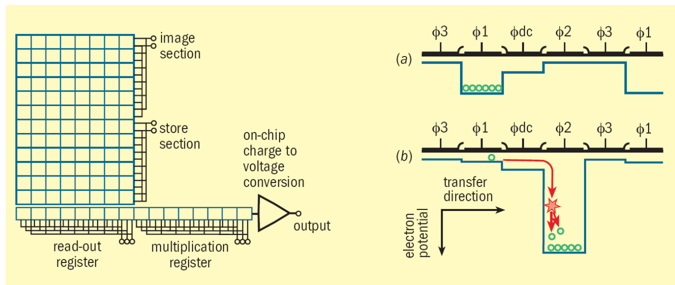
- Kompaktsatellit: best-of micro and mini satellites in a new 100…150 kg class
- designed for scientific payloads from within DLR, on a bus tailored to science requirements
- evolution towards a flight-proven set of subsystems and design variations, as a Standard Satellite Bus kit, /SSB



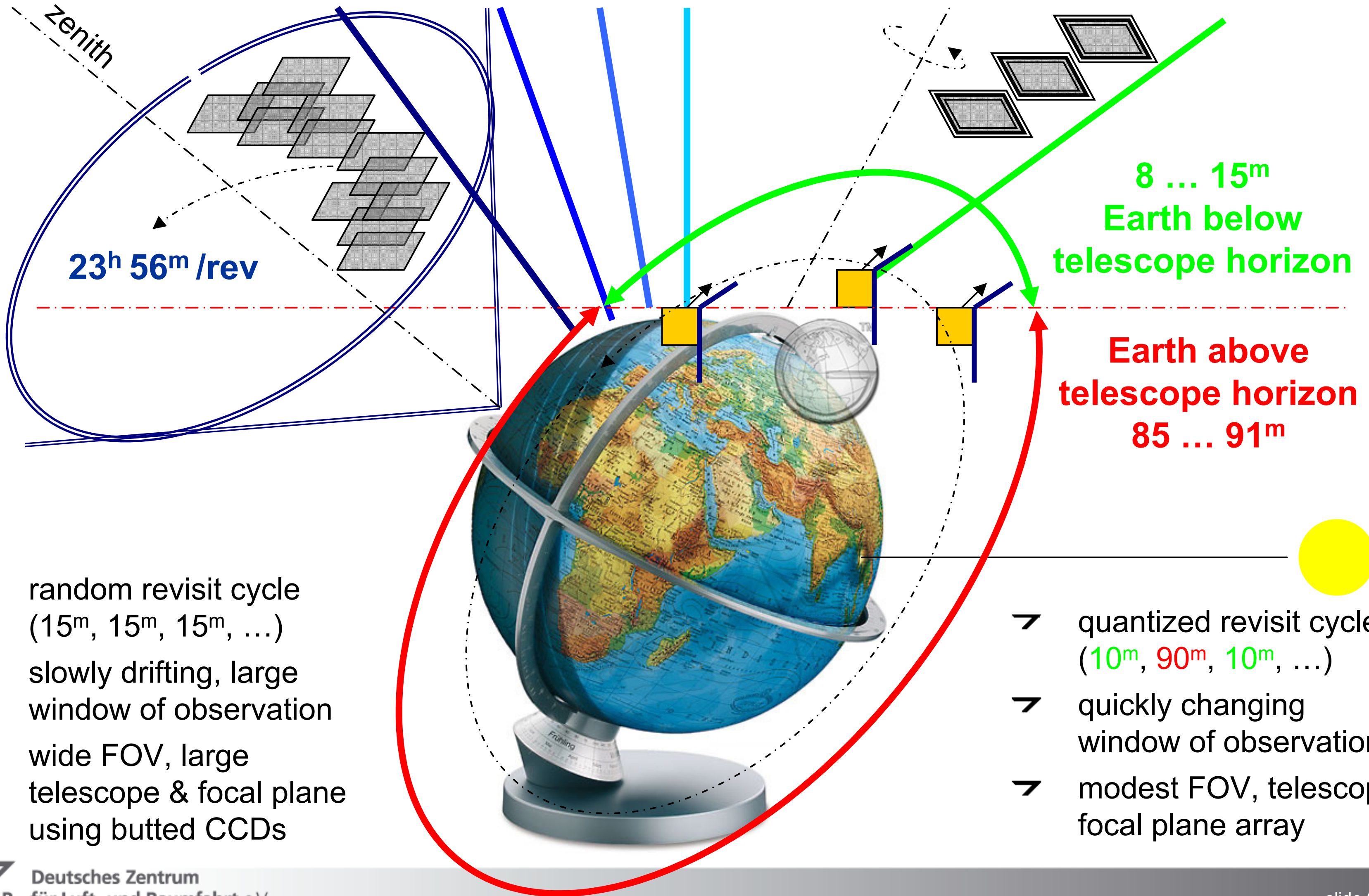
the instrument: advanced optics and electronics

- limiting magnitude V $\geq$ 18.5 mag @ 1 min
- FOV = 2°x 2°, astrometric accuracy ~1…1.5"
- off-axis telescope design
  - high straylight suppression
    - Sun : asteroid ~ 10^{18} : 1
    - planet : asteroid ~ 10^{8} : 1
    - asteroid : background ~ 4 : 1
- electron-multiplied CCD sensors
  - fast read-out noise suppression
  - high flexibility in exposure timing and signal processing
  - registered stacking of ~ 5 frames/s to remove cosmics and satellite jitter
- area coverage & resolution → high data rate





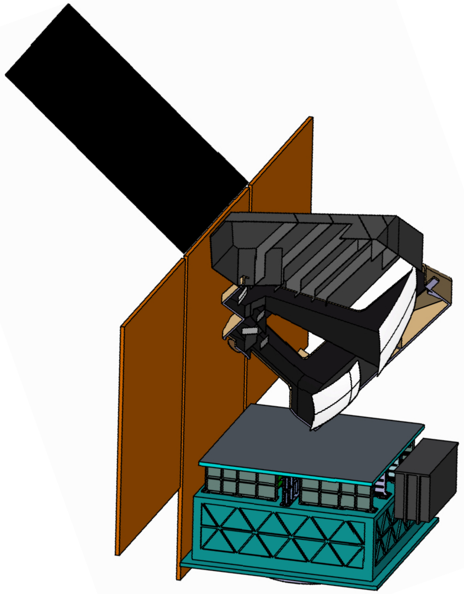
from the ground up: motion detection & orbital motion



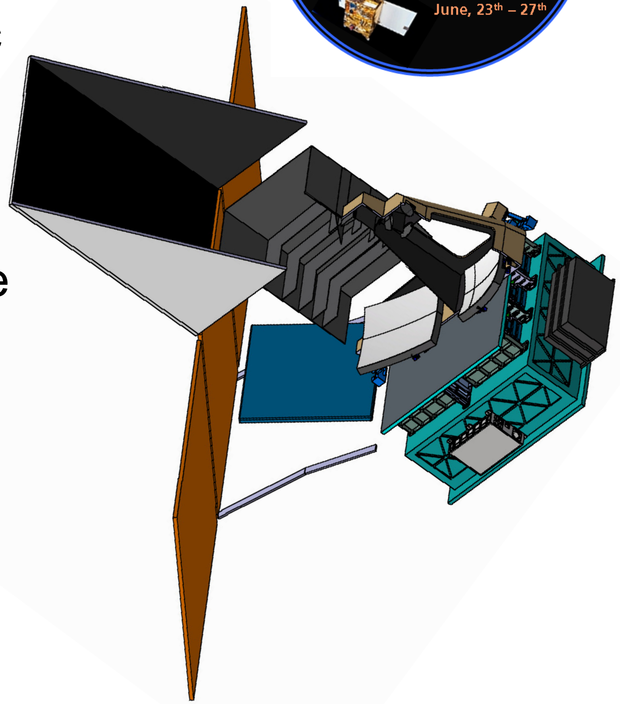
- random revisit cycle (15^m, 15^m, 15^m, …)
- slowly drifting, large window of observation
- wide FOV, large telescope & focal plane using butted CCDs

- quantized revisit cycle (10^m, 90^m, 10^m, …)
- quickly changing window of observation
- modest FOV, telescope, focal plane array

taking shape: deep exposures in the light of day



- detecting sub-km asteroids at low elongations is feasible
- advanced design of the scientific payload combined with proven small satellite technology enables a cost-effective solution
- satellite orientation relative to the Sun and Earth is strongly coupled to thermal and optical sensitivities
- thorough end-to-end simulations are required very early in the project to iterate towards the best-performing overall design



Questions?

Who knows whether, when a comet shall approach this globe to destroy it, as it often has been and will be destroyed, men will not tear rocks from their foundations by means of steam, and hurl mountains, as the giants are said to have done, against the flaming mass? - And then we shall have traditions of Titans again, and of wars with Heaven.

Lord Byron, 1822

image credits: J.Hartmann M.Lieder DLR, G. Hahn DLR-EARN, ESA,NASA, astronautix.com, Sandia Labs, Kayser-Threde, geosmile.de; partially obtained via wikipedia

Supplementary Slides: Asteroid 101

- The Sky is the Limit – in Detail
- Space is not Unlimited
- Motion Detection
- Summed Up

Asteroid 101: The Sky is the Limit – in detail

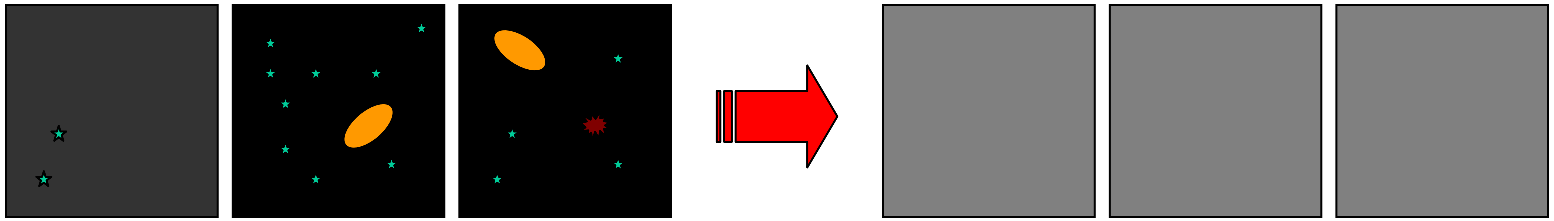
Weather	clouds, haze, water vapour	<	18 km
Blue Sky	scattered sunlight and moonlight	<	80 km
Sky Glow	emission lines of excited molecules	<	250 km *
SatelLight	gas discharge around spacecraft	<	500 km
Air Glow	faint equatorial aurora	<	700 km *
Aurora	bright polar aurora oval	<	1000 km *

- ***) upper limit dependent on solar activity – *2011/12 is solar maximum*!**

Asteroid 101: Space is not Unlimited

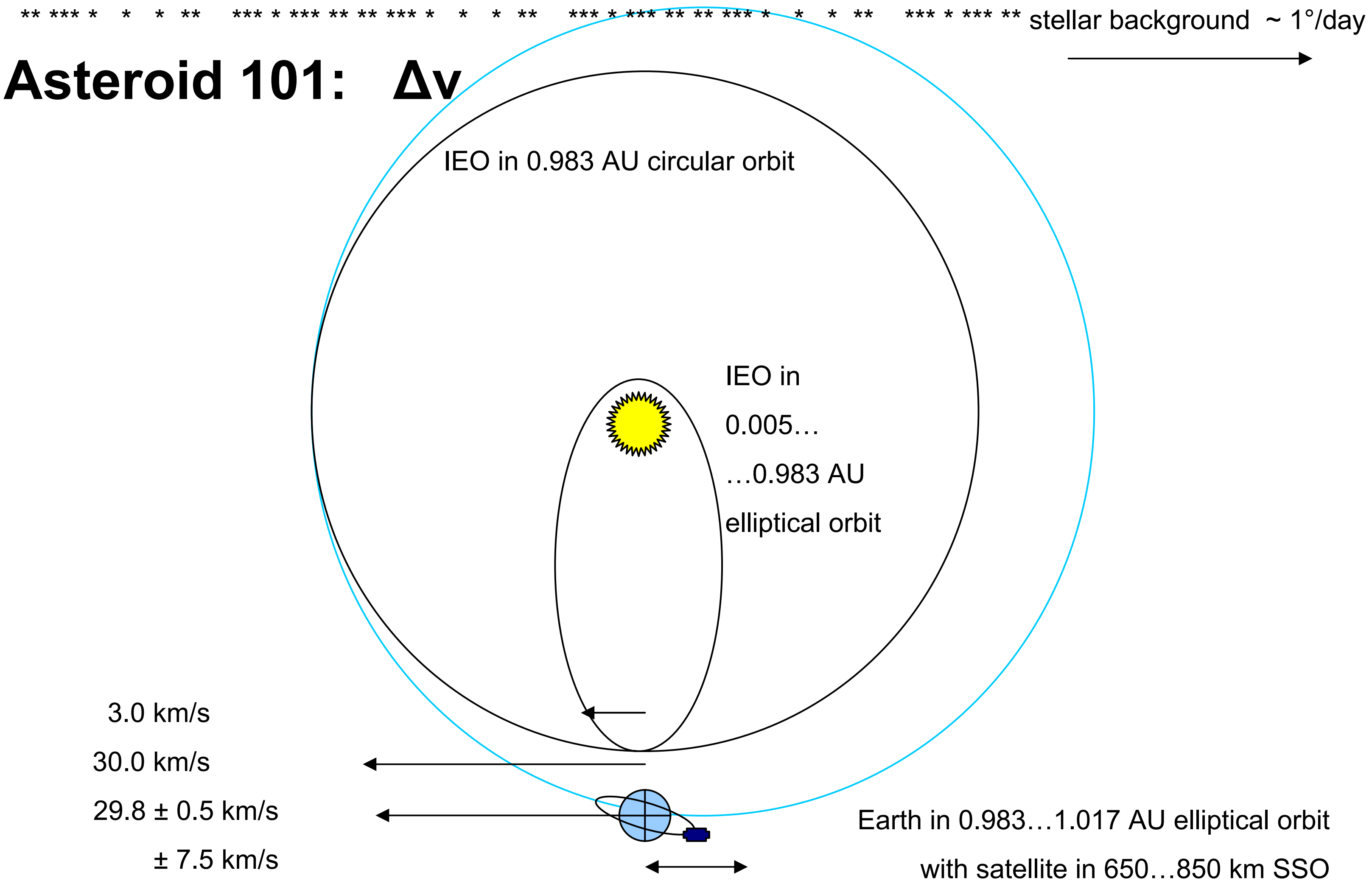
- stars and nebulae form a distant diffuse background at any resolution (“Billions and Billions”)
- interplanetary dust forms a local background that moves around the Sun (Zodiacal light, Lunar L4/5 dust clouds)
- the corona forms a variable background centered on the Sun, even beyond the area out to 32 solar radii covered by SOHO LASCO C-3

On camera, at any given pixel scale,…

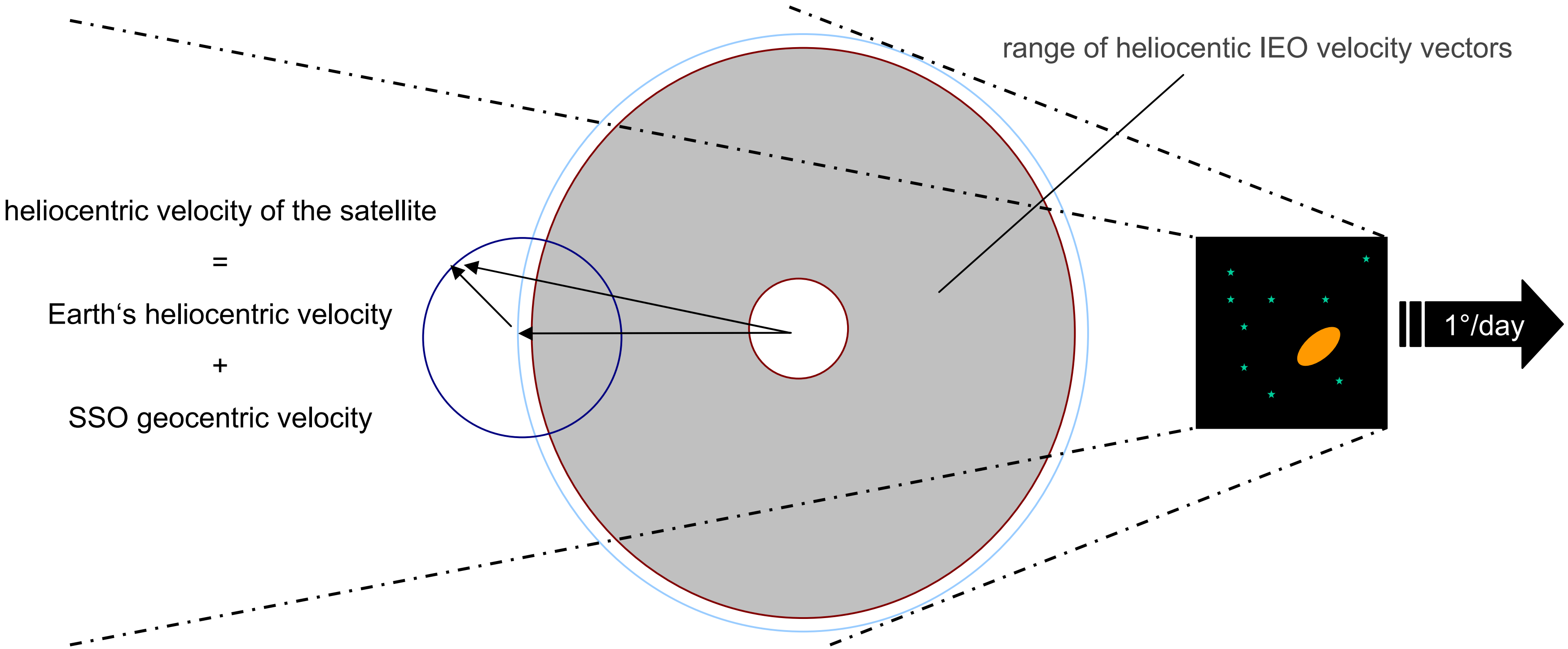


…diffuse background, stellar background, or passing asteroid may…   *…READ EXACTLY THE SAME*

Asteroid 101: Δv



Asteroid 101: Δv projected



- Zero relative velocities and angular rates are possible, with a few to a few hundred arcseconds/minute being typical
- Impossible to catch all at any time

Asteroid 101: easily over-optimized

- SNR: Keep area covered by pixel tiny
- Yield: Keep area covered by telescope huge
- Catch all sizes: Keep the shutter open for a long time
- Catch all orbits: Watch again and again

- *Get yourself a huge data volume*

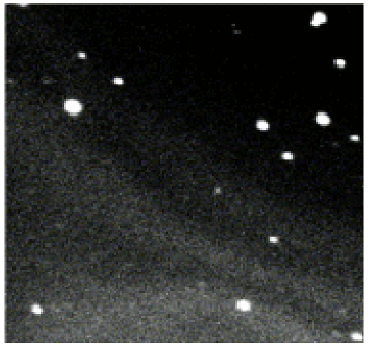
Asteroid 101: …Finder/SSB summed up

- detector: $(1K)^2$, ≤ 16 bit/pixel, ≥ 58 ms exposure, EMCCD, no filters
- $(2°)^2$ FOV, 4 independent channels, pixel scale ~ 3'' / pixel
- motion detection threshold 2..5 pixels
- ~ 10'' / >100 min ≤ angular motion detection limit ≤ ~ 2°.4 / 1 min
- expected yield: ~ 40 IEO's and ≥ 115000 Gbit raw data per year
- recently, a dust ring just outside the orbit of Venus was discovered in Helios solar probe single pixel photomultiplier sensor raw data from 1974
  - *Raw data are and remain valuable*!
- such as… main belt asteroids, Kuiper belt objects, supernovae, GRB afterglows, interplanetary dust background, exo-planet occultations, variable stars, fast-moving stars, and stellar background in general…

Asteroid 101: IEOs, NEOs, Mitigation FAQ resources

- Gerhard Hahn, DLR EARN asteroid database: http://earn.dlr.de/nea/ *(provides population graph in slides #2,3)*
- IAU: Minor Planet Center – Lists and Plots: Minor Planets: http://cfa-www.harvard.edu/iau/lists/MPLists.html
- NEODyS Near Earth Objects Dynamic Site: http://newton.dm.unipi.it/cgi-bin/neodys/neoibo
- Don Yeomans, NASA NEO Program – Current Impact Risks: http://neo.jpl.nasa.gov/risk/
- David Vokrouhlický, Paolo Farinella and William F. Bottke, Jr.; The Depletion of the Putative Vulcanoid Population via the Yarkovsky Effect, Icarus Volume 148, Issue 1, Nov. 2000, p. 147-152 *(google by title)*
- Patrick Michel, Vincenzo Zappalà, Alberto Cellino, Paolo Tanga; Estimated Abundance of Atens and Asteroids Evolving on Orbits between Earth and Sun, Icarus Volume 143, Issue 2, Feb. 2000, p. 421-424 *(google b.t.)*
- William F. Bottke, Jr., Alessandro Morbidelli, Robert Jedicke, Jean-Marc Petit, Harold F. Levison, Patrick Michel and Travis S. Metcalfe; Debiased Orbital and Absolute Magnitude Distribution of the Near-Earth Objects, Icarus Volume 156, Issue 2, Apr. 2002, p. 399-433 *(provided population data - google by title)*
- Tunguska Home Page, University of Bologna: http://www-th.bo.infn.it/tunguska/ → Publications
- Michael J.S. Belton, Thomas H. Morgan, Nalin H. Samarasinha, Donald K. Yeomans (ed.), Mitigation of Hazardous Comets and Asteroids, Cambridge University Press, 2004
- Spaceguard Foundation: http://spaceguard.rm.iasf.cnr.it/SGF/INDEX.html http://www.spaceguarduk.com/
- Chrisian Gritzner, Kometen und Asteroiden – Bedrohung aus dem All, Aviatic Verlag (1999)
- Ralph Kahle, Modelle und Methoden zur Abwendung von Kollisionen von Asteroiden und Kometen mit der Erde, Doctoral Thesis, Technische Universität Berlin (2005): http://opus.kobv.de/tuberlin/volltexte/2005/1127/pdf/kahle_ralph.pdf , this and more at http://www.weblab.dlr.de/rbrt/Publications/PubKahle.html
- Jan Thimo Grundmann, Betrachtung des Missionsszenarios zur Verhinderung von Einschlägen von Asteroiden auf die Erde unter Berücksichtigung des Bedrohungspotentials und der technischen Möglichkeiten, diploma thesis, RWTH Aachen (2006): http://www.kiwikommando.de/space4space/ *(provisional)*

Asteroid 101: The Devil is in the Details



(99942) Apophis

…named after the Ancient Egyptian Uncreator who dwells in the eternal darkness of the underworld. A close Earth flyby on Fri 13 Apr 2029 below geostationary altitude will gravity-assist Apophis for anything between a ~0.1 AU miss and a dead centre Earth impact on 13 Apr 2036, at 2.2E-5 estimated probability.

Hint: (99942) + ✂ + ↶↷ → ‘666’ + 42 ;-)